η': Status update on $B^0 \to \eta' K^0_S$ on DataChallenge

and rediscovery in phase II

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Summary

- η' **rediscovery on phase2**
- $B^0 \to \eta' K^0_S$ analysis for DataChallenge

η' rediscovery: Note available **BELLE2-NOTE-PH-2018-038**

Dataset

- **Data** exp3, Prod6, skim Hadron `[[nTracksLE>=3] and [Bhabha2Trk==0]]`
- **MC phase2** $q\bar{q}$ continuum events
- **MC phase3** Data Challenge; TDCPV skims (light resonance η, η', ρ, ϕ plus K^0_S)

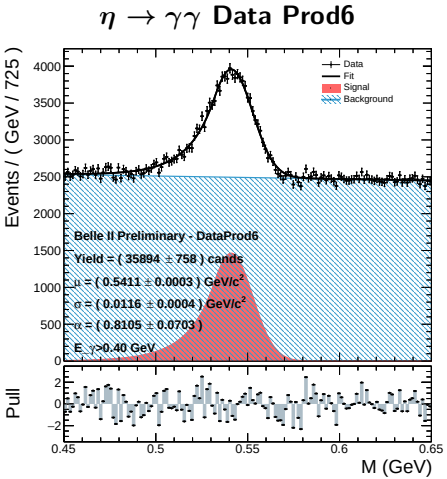
channel considered for η'

- $\eta' \to \eta(\to \gamma\gamma)\pi^+\pi^-$
- $\eta' \to \eta(\to \pi^+\pi^-\pi^0)\pi^+\pi^-$
- $\eta' \to \rho(\to \pi^+\pi^-)\gamma$

other light resonance discussed in the note $\pi^0, \eta(\to \gamma\gamma, 3\pi), \phi, K^0_S, \rho, f_0$

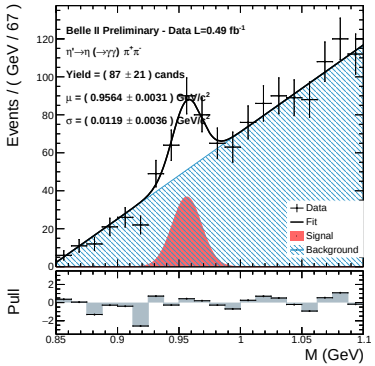
$\eta' \to \eta(\to \gamma\gamma)\pi^+\pi^-$

- $\pi^{\pm}$
  - $|d_0(\pi)| < 2\ cm$, $|z_0(\pi)| < 4\ cm$
  - $PionID > 0.5$, $KaonID < 0.5$
  - $p_\pi > 200$ MeV
- $\eta \to \gamma\gamma$
  - Cluster: $N_{hits} > 5$, $E_9/E_{21} > 0.93$
  - $450\ \text{MeV} < E_\gamma < 6\ \text{MeV}$
  - $0.5 < M_{\gamma\gamma} < 0.62$ GeV
- η
  - $520 < M_\eta < 580$ MeV
  - $p_\eta > 700$ MeV
- `VertexTree` for $\eta \to \gamma\gamma$

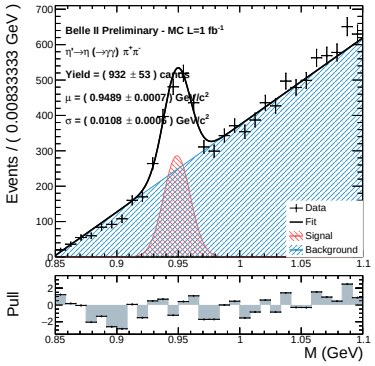


$\eta' \to \eta(\to \gamma\gamma)\pi^+\pi^-$ Data - MC comparison

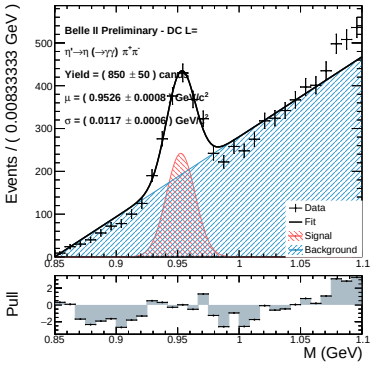
Data - Phase 2



MC - Phase 2 BGx1



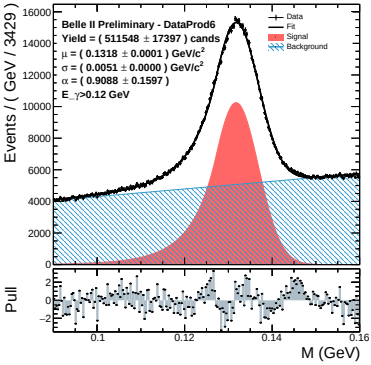
DC - Phase 3 BGx1

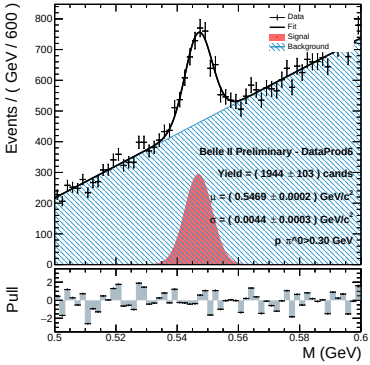


(similar to previous presentation) MC and DC ok, σ wider in DC.
Small signal on Data, larger σ 18 vs 11 MeV

- $\pi^0 \to \gamma\gamma$
  - Cluster: $N_{hits} > 1.5$, $E_9/E_{21} > 0.91$
  - $50\,\text{MeV} < E_\gamma < 6\,\text{GeV}$
  - $125 < M_{\pi^0} < 150\,\text{MeV}$
  - $p_{\pi^0} > 100\,\text{MeV}$
- $\pi^\pm$
  - $|d_0(\pi)| < 2\ cm$, $|z_0(\pi)| < 4\ cm$
  - $PionID > 0.5$, $KaonID < 0.5$
  - $p_\pi > 100\,\text{MeV}$
- η
  - $510 < M_\eta < 590\,\text{MeV}$
  - $p_\eta > 150\,\text{MeV}$
- `VertexTree` for $\pi^0 \to \gamma\gamma$ and $\eta \to 3\pi$

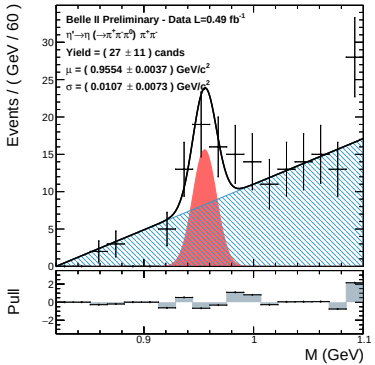
$\pi^0 \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ Data Prod6



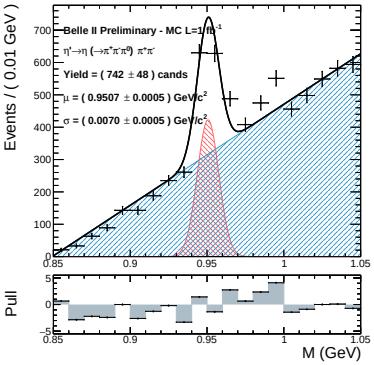


$\eta' \to \eta(\to \pi^+\pi^-\pi^0)\pi^+\pi^-$ Data - MC comparison

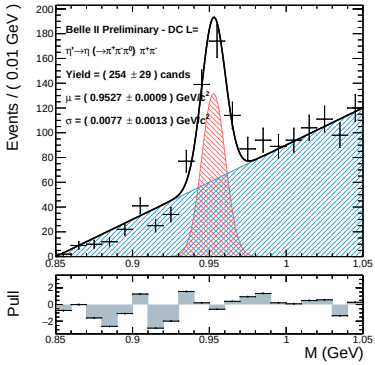
Data - Phase 2



MC - Phase 2 BGx1



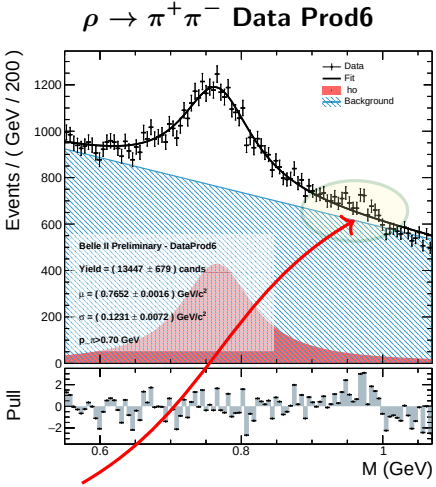
DC - Phase 3 BGx1



Now MC (new) and DC are as expected.
Maybe signal on Data, very low significance and background shape not trivial
(and not well modelled by fit)

$\eta' \to \rho(\to \pi^+\pi^-)\gamma$

- $\rho \to \pi^+\pi^-$
  - $PionID > 0.5$, $KaonID < 0.5$
  - $p_\pi > 0.3\,\text{GeV}$
  - $0.470 < M_\rho < 1.07\,\text{GeV}$ before fit
  - $0.65 < M_\rho < 0.9\,\text{GeV}$ after fit
- γ `gamma:all` from `stdPhotons`
  - $0.296706 < \theta < 2.61799$
  - Cluster: $N_{hits} > 1.5$, $E_9/E_{21} > 0.91$
  - $500\,\text{MeV} < E_\gamma < 6\,\text{GeV}$
  - **Pi0Veto**
    - ★ no γ in ROE with $|M_{\gamma\gamma} - M_{\pi^0}| < 20\,\text{MeV}$
- $p_{\eta'} > 0.2\,\text{GeV}$
- `VertexTree` for $\rho \to \pi^+\pi^-$



Possibly $f_0(975) \to \pi^+\pi^-$

$\eta' \to \rho(\to \pi^+\pi^-)\gamma$

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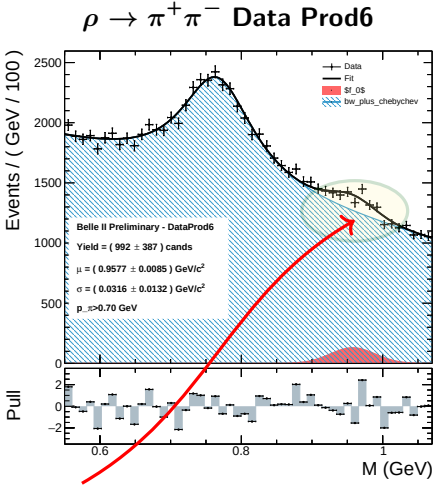
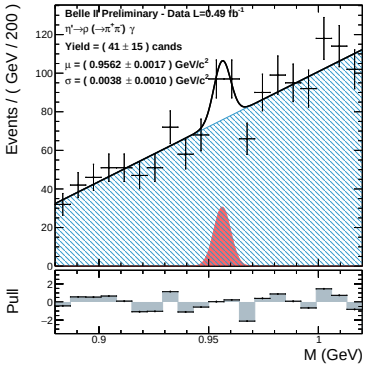


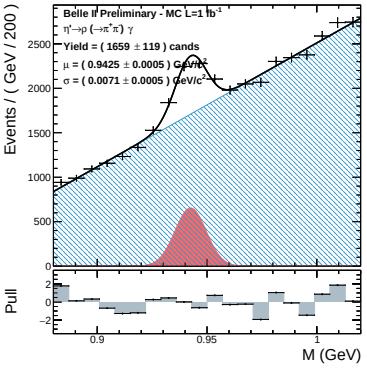
Possibly $f_0(975) \to \pi^+\pi^-$

$\eta' \to \rho(\to \pi^+\pi^-)\gamma$ Data - MC comparison

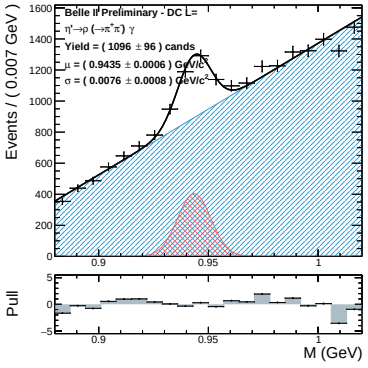
Data - Phase 2



MC - Phase 2 BGx1



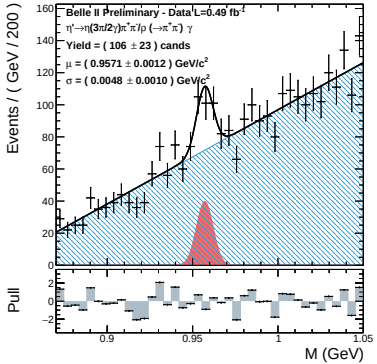
DC - Phase 3 BGx1



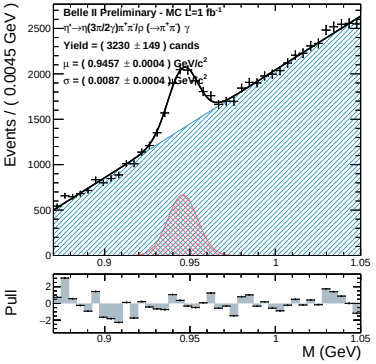
Now MC and DC are as expected (was not). Mass peak ~ 8 MeV lower than other channels.
On Data hard to say (was none), very low significance and very narrow ?

Combined η' Data - MC comparison

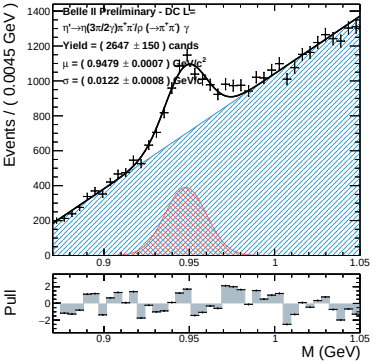
Data - Phase 2



MC - Phase 2 BGx1



DC - Phase 3 BGx1



On Data the peak is good, still very narrow (due to $\rho\gamma$?).
10 MeV bias of Data wrt MC.
In DC (and MC) combined peak width is also due by lower peak position in $\rho\gamma$ channels.
Not so in data.

Intro (II)

Summary

- η' rediscovery on phase2
- **$B^0 \to \eta' K^0_S$ analysis for DataChallenge**

Quick reminder of $B_0 \to \eta' K_s$ analysis strategy for DataChallenge

- ✓ Signal selection and eff estimation (MC)
- ✓ continuum background suppression
- ✗ Signal cross Feed (SxF) optimization
- 🔧 ML fit to extract signal yield (and compute BR)
- 🔧 Toy study with expected yield to assess resolution and bias
- 🔧 study Δt and Δz resolution in MC, including modelization
- ✗ ML fit to Data challenge to extract TDCPV parameters

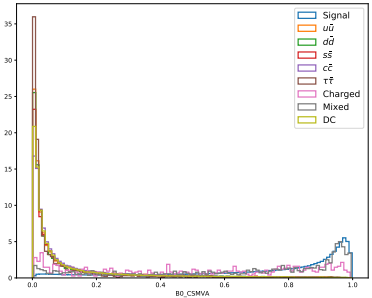
DC $B^0 \to \eta' K^0_S$: TDCPV

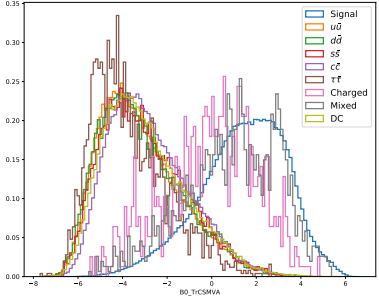
Work done so far

- **Still only $B^0 \to \eta'(\to \eta_{\gamma\gamma}\pi^+\pi^-)K^0_S(\to \pi^+\pi^-)$**
- Moved back to MC9 (was MC10 only)
  - DC is based on MC9 `release-01-0x-xx`
  - ✓ signal (BGx0, BGx1), also MC10 BGx1 for comparison
  - ✓ background ($q\bar{q}$, $B\bar{B}$ generic, τ): BGx1, 0.8 ab^{-1}
- Continuum suppression re-implemented and re-trained
- check also sibling channel $B^+ \to \eta' K_s$ for cross check;
- First look at DC: search for signal and first yield estimation;
  - Many issues found, will discuss later.

Continuum suppression

- Got wrong in first iteration (that's why I got no signal!)
- re-trained using signal events (MC9 BGx1) against continuum $q\bar{q}$ passing preselection;
  - Still working with `NtupleTools`, will move to `VariableToNtuple` sometime;
- I prefer to use Transformed CS-MVA rather than prob since it is easier to model in ML fit.
- TODO: use Data (DC) side bands as training sample





warning: mixed have also signal inside: removed for final selection

Signal Efficiency

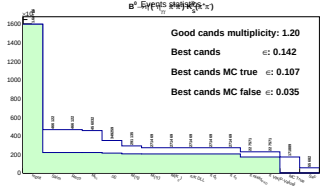
Dataset	ε %	SxF%	cand/ev
MC9 BGx0	22.1	3.5	1.2
MC9 BGx1	10.7	4.8	1.14
MC10 BGx1	21.7	6.7	1.2
B2TIP BGx0	30.1	2.3	1.06
B2TIP BGx1	23.0	3.8	1.09

Same selections: $\varepsilon_{MC9} << \varepsilon_{MC10}$

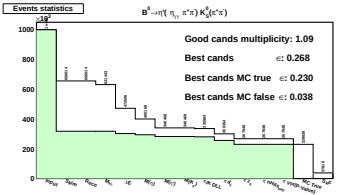
DC is based on MC9

Investigating if something wrong in B-field GT

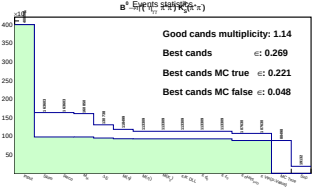
MC9 BGx1



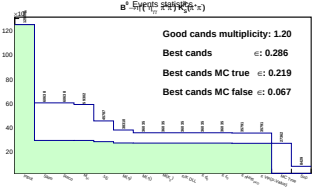
MC7 BGx1 (B2TIP)



MC9 BGx0



MC10 BGx1



Warning: some selection (*eg* $M_{\eta,\eta'}$) moved to pre-selection wrt B2TIP

Signal yield expected

- Reporting B2TIP table
- event yield for background looking at $0.8\,\text{ab}^{-1}$ of MC9, rescaled to $1\,\text{ab}^{-1}$
  - continuum a bit higher, but compatible
  - peaking lower for neutral (/10) and higher for charged (x4)
  - signal is removed from neutral mixed
- signal expected given the (low) ε in MC9
  - Was $\sim$ 970 events, $\varepsilon \sim 23\%$
  - in MC9 expect $\sim$ 350 events.
  - from $0.8\,\text{ab}^{-1}$ of generic $B^0\overline{B}^0$ I got $\sim$ 316 true signal
    - ⋆ **$\sim$ 400 in $1\,\text{ab}^{-1}$**

L=1 ab^{-1}

	B2TIP	MC9	DC
	N ev.		
$q\bar{q}$	16413	18300	-
$B^0\overline{B}^0$	1834	150	-
B^+B^-	57	210	-
Signal	969	400	-
Total	$\sim$ 20 000	$\sim$ 19 000	**6150**

Even before searching for the signal, I do have roughy 1/3 of the continuum events I do expect
And (in principle) MC9 and DC are the same thing.

TDCPV skims

- I'm always using the TDCPV skim centrally produced;
- not for the signal, where I run my selection w/o intermediate skim;
- Check the event yields and retention rate ε after the TDCPV skims
  - not clear to me if these numbers refer to 1 or $0.8\,\text{ab}^{-1}$

	MC9			DC		
Dataset	all	skim	ε	all	skim	ε
$q\bar{q}$	$4.6 \cdot 10^9$	$213 \cdot 10^6$	4.6%		-	
$B^0\overline{B}^0$	$0.53 \cdot 10^9$	$3.5 \cdot 10^6$	0.67%		-	
B^+B^-	$0.56 \cdot 10^9$	$4.6 \cdot 10^6$	0.8%		-	
Total	$5.7 \cdot 10^9$	$221 \cdot 10^6$	3.8%	$5.6 \cdot 10^9$	$60 \cdot 10^6$	1%

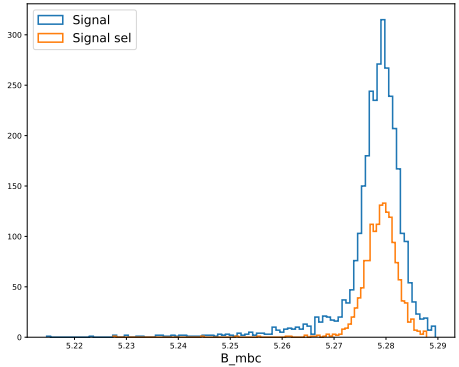
What am I missing?
It seems that the initial numer of events is correct, but the TDCPV skims retains about 1/4 of what I would expect.

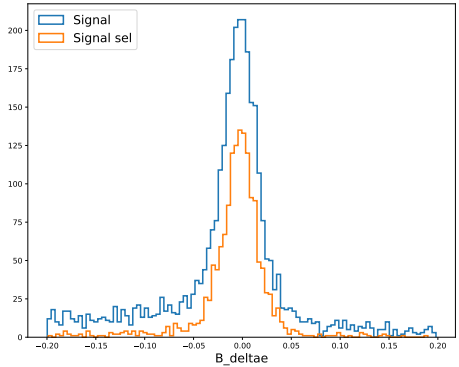
Intermezzo $B^+ \to \eta' K^+$

- Why B^+?
  - The idea was to have a control channel with similar final state
  - (thanks Ale for the suggestion)
- BR is similar: $\mathcal{B}(B^+) = 4.1 \cdot 10^{-6}$ vs $\mathcal{B}(B^0) = 3.86 \cdot 10^{-6}$
- no MC available (not even dec file)
  - produce and test a dec file
    - ✗ **pro tip**: if you ask EVTGEN to decay $\eta' \to \eta' \pi^+ \pi^-$, it will do it w/o complaining.
  - produced privately 10k events (release-02-01-00)
  - setup a quick and dirty selection:
    - ⋆ η' as in B^0 channel, plus a K^+
  - ε roughly 33% reconstruction and preselection
  - $\varepsilon \sim 15\%$ with cut on $M_{\eta,\eta'}$ and $CS_{MVA} > 0.5$
  - rescale by factor 2? for MC10→MC9? $\varepsilon \sim 7 - 10\%$
- expected yield in $1\,ab^{-1}$: $1.1 \cdot 10^9 (B\overline{B})$, $550 \cdot 10^6 (B^+B^-)$
- Yield $= N_{B^+B^-} \cdot 2 \cdot \mathcal{B} \cdot \varepsilon \approx 300 - 400$ events in $1\,ab^{-1}$
  - side note: almost as hard as the signal channel...

Intermezzo (II) $B^+ \to \eta' K^+$

M_{bc} and ΔE for privately produced $B^+ \to \eta' K^+$
[selection] is w/ cut on $M_{\eta,\eta'}$ and $CS > 0.5$

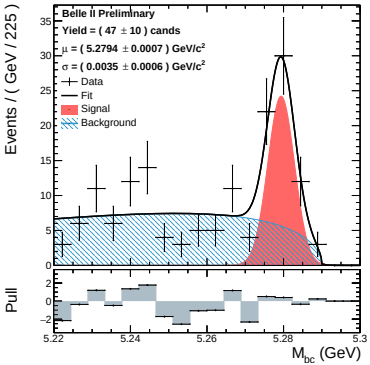




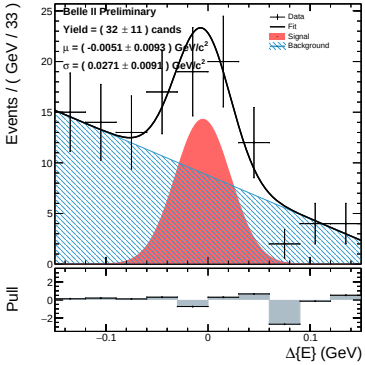
Intermezzo (III) $B^+ \to \eta' K^+$

- Not a 2D ΔE, M_{bc} MI fit: only 1D
- selection:
  - $M_{\eta,\eta'}$
  - $CS > 0.5$
- found a nice signal in DC in M_{bc} distribution and ΔE
- event yield $\sim 30 - 50$
  - Expected $\sim 300 - 400$
  - why?

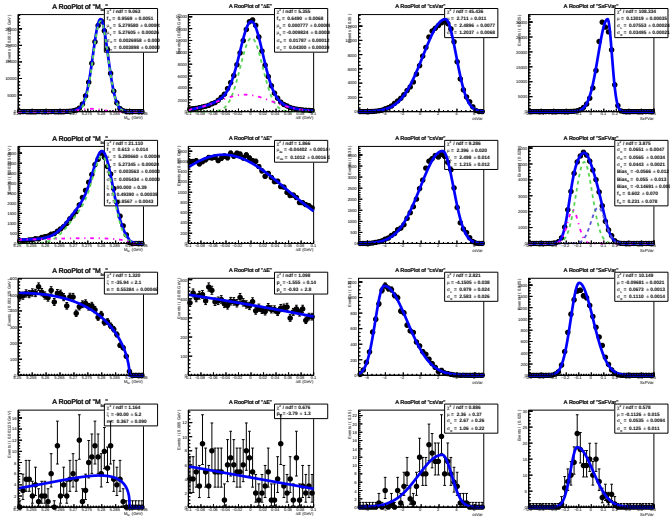
$|\Delta E < 0.1|$



$M_{bc} > 5.26\,\text{GeV}$



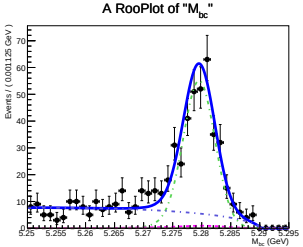
Back to B^0 ML fit: w/o the time dependent part

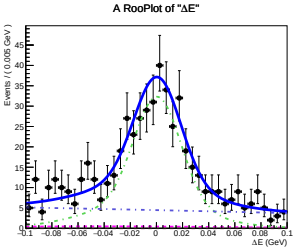


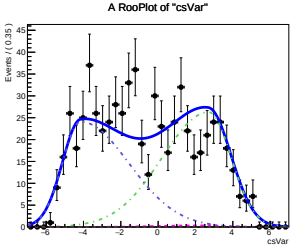
Back to B^0

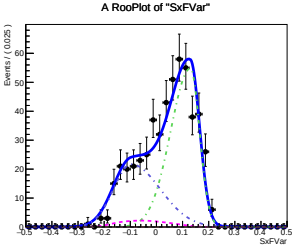
- Columns:
  - M_{bc}
  - ΔE
  - CS_{MVA}
  - SxF_{MVA} not retrained yet
- Rows:
  - Signal
  - SxF
  - continuum
  - peaking signal removed

Signal B^0 in MC9









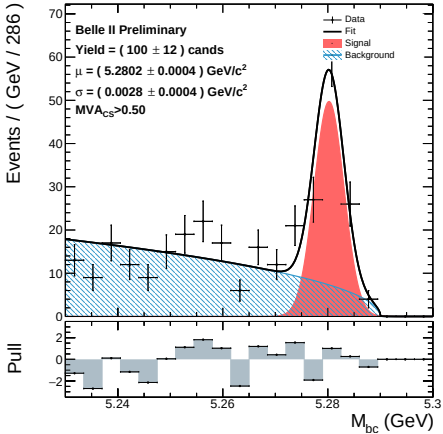
B^0 in MC, not yet DC

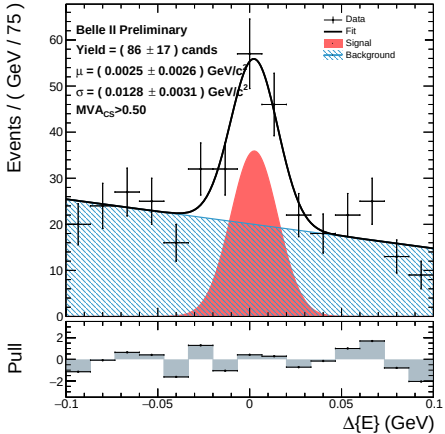
- Build my own "DC"[a],
  - combining $0.8\,\text{ab}^{-1}$ of continuum
  - and $0.8\,\text{ab}^{-1}$ $B\,\overline{B}$
    - w/o removing my signal
- MC truth tells me that I do have $\sim$ **320** `B0_isSignal`
- ML fit found:
  - **nSig=407** (30σ)
  - **nSxF=57.8** (1.2σ)
  - bias to be investigated, might be related to bad SxF MVA

[a] with blackjack and h... [Bender Bending Rodríguez, Futurama, ep. 2, s. 1]

Signal B^0 in DC proper (allegedly $1\,ab^{-1}$): 1D ML fit

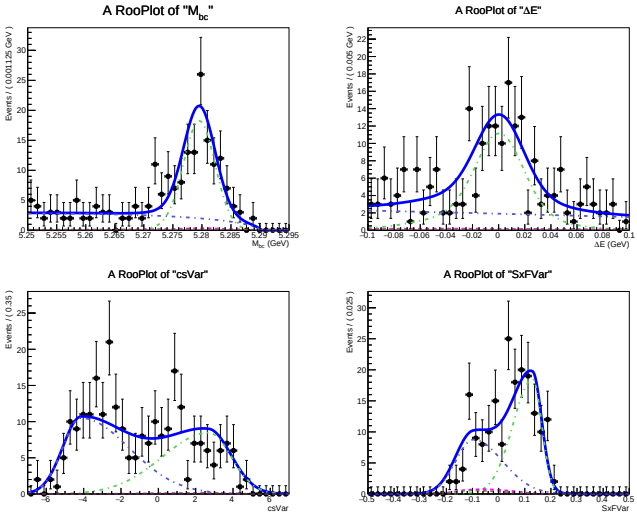
First just try to apply all selection plus $CS_{MVA} > 0.5$ and perform a 1D fit on M_{bc} and ΔE





Expected event yield ~ 400 events

Signal B^0 in DC proper (allegedly $1\,ab^{-1}$): 4D ML fit



The full 4D ML fit and signal extraction

- ML fit found:
  - **nSig=136.6 ± 14.7 ev** (16σ)
  - **nSxF=22.2 ± 33.1 ev** (0.7σ)
- expected $\sim$ 400 events
- A good signal, but significantly lower than expected
  - signal is roughly 1/4 of expected, as the ratio between TDCPV skimmed events
  - worth investigating...

Summary and todo

Summary

- ✓ Found small signal for $\eta' \to \eta(3\pi/2\gamma)\pi^{\pm}/\rho\gamma$ in Phase II Data
- ✓ Found signal for both $B^+ \to \eta' K^+$ and $B^0 \to \eta' K^0_S$ in DC
- ✗ both significantly lower than expected
- ✓ hand-made $0.8\,ab^{-1}$ DC mixture has the expected number of signal events

Todo

- Understand TDCPV skims retention in DC
- Understand if I'm using the correct B-field
- Do SxF retraining (and/or try if π^0 veto improves SxF)
- toys for ML fit for signal yields to check bias
- a better control channel?

Additional stuff

Additional or backup slides